Comment on "Experimental Demonstration of the Time Reversal Aharonov-Casher Effect"

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In a recent Letter [1], Bergsten et al. have studied the resistance oscillations with gate voltage V_g and magnetic field B in arrays of semiconductor rings, and interpreted the oscillatory B-dependence as Altshuler-Aronov-Spivak oscillations and oscillatory V_g-dependence as the time reversal Aharonov-Casher (AC) effect. This comment shows (i) that authors [1] incorrectly identified AAS effect as a source of resistance oscillations with B, (ii) that spin relaxation in [1] is strong enough to destroy oscillatory effects of spin origin, e.g., AC effect, and (iii) the oscillations in [1] are caused by changes in carrier density and the Fermi energy by gate, and are unrelated to spin.

AAS effect is the $h/2e$ oscillations of conductance with B in disordered diffusive rings. Oscillations occur because the interereference of the two electron trajectories passing the whole ring clock- and counterclockwise survives disorder averaging in conditions of diffusive regime $l \ll L_\phi, L$, where l is the mean free path, L_ϕ is the phase breaking length, and L is the circumference of the ring.

The mean free path in samples [1] is $l \sim 1.5-2\,\mu m$. From the ratio of h/2e and h/4e signal amplitudes [1], L_ϕ is between 2.8 and 3.5 μm. (Note that $h/2e$ signal is due to interference of clockwise and counterclockwise paths, with magnitude defined by $\exp(-2L/L_\phi)$, and $h/4e$ oscillations are due to interference of paths going twice clockwise and twice counterclockwise, defined by $\exp(-4L/L_\phi)$. The calculation of L_ϕ in [1] misses a factor of two.). Thus, samples [1] are not in diffusive regime relevant to AAS oscillations, but are in the quasi-ballistic regime $l \lesssim L$. Then $h/2e$ oscillations are defined not only by interference of time-reversed paths, but also e.g., by the interference of the amplitude of propagation through the right arm clockwise and the amplitude of propagation via the three-segment path: the left arm, the right arm (counterclockwise) and again through the left arm. With all interference processes included, $h/2e$ oscillations depend on the Fermi wave-vector and n_s [2],[3]. Averaging over few resistance curves does not eliminate contributions of of non time-reversed processes (certainly not beyond 0.3% of the overall signal for oscillations in [1]). Their importance is missed in [1] and is crucial.

(ii) Another mistake in [1] is the neglect of spin relaxation. For the spin-orbit constant $\alpha = 5\,\text{peV·m}$, the parameter $\alpha m l \sim 2.5$ (m is the effective mass), and spin simply flips due to a single scattering event. The spin-flip length $L_S = l < L$. Thus, oscillations of spin origin are rather unlikely in [1]. The closest to [1] feasible setting requires ballistic regime $l \gg L$ [3], which requires mobility an order of magnitude higher. Note that $L_\phi > L_S$ and oscillations with B originating from charge coherence are plausible to observe.

(iii) The key to understanding the $h/2e$ oscillations with V_g in [1] is its Fig .4. It can be seen clearly that resistance oscillations are present only when n_s changes with V_g, and are not present when n_s saturates. Therefore the reason for the observed oscillations is the variation of the n_s. Oscillations of spin origin, particularly the AC effect, must persist when n_s is constant, while α varies with V_g. No such evidence is present in [1].

The origin of oscillations with n_s is the contribution to $h/2e$ signal from interference of non-time reversed paths. These are independent of L_S, and are governed by $L_\phi > L_S$. That makes this effect dominant over any spin oscillations. With the account of the role of contacts connecting the ring and the leads [2],[3], in the absence of spin-orbit interactions and for strong coupling of leads and rings, the conductance of the single ring is

$$G = \frac{2e^2}{h}\left[1 - \left|\frac{1 - \cos(\pi\Phi/\Phi_0)}{1 - e^{ik_F L}\cos^2(\pi\Phi/\Phi_0)}\right|^2\right] \quad (1)$$

We note that disregard of transmission and reflection from contacts is yet another critical omission in [1], whose equation for conductance is incorrrect in ballistic/quasi-ballistic regime. (It is also incorrect for AAS and AC effect in diffusive regime). The second harmonics in (1) depends on k_F and n_s in an oscillatory manner, leading to oscillations of conductance with V_g. The system of the n interconnected rings can be described similarly to the setting in [4]. On Fig. 1, we show the dependence of the amplitude of the second harmonic on k_F for one and four rings. Conductance oscillates with electron density despite no spin effects are involved. To summarize, conclusions of [1] on the observation of the AC effect are unfounded.
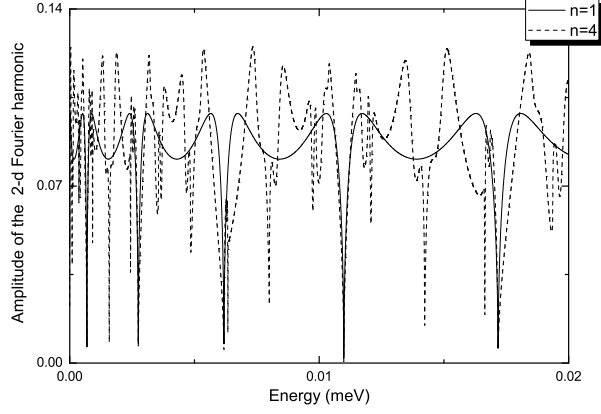
FIG. 1: The amplitudes of the second harmonics in a single ring (solid curve) and four consequently connected rings (dashed curve). The spin-orbit interaction is absent.

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